Virginia Wildrye Evaluated as a Potential Native Cool-Season Forage in the Northeast USA

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ABSTRACT

Most forage grasses grown in the northeastern USA are introduced species. Interest in native plant species for conservation and production has increased because of new federal policies. We evaluated northeastern accessions of the native cool-season grass Virginia wildrye (*Elymus virginicus* L.) for yield, persistence, and plant morphological traits. Thirteen accessions, one cultivar (Omaha), and one commercial ecotype of *Elymus* were transplanted into single-row field plots in late summer of 2000 at Beltsville, MD, Rock Springs, PA, and Big Flats, NY. Two orchardgrass (*Dactylis glomerata* L.) cultivars were the checks. Yield and morphology (leaf width, length, mass, area, and tillers per plant) data were collected during 2001 and 2002. The *Elymus* accessions produced as much dry matter (28–57 g per plant) as the cultivar and commercial ecotype. Orchardgrass yielded more than twice as much dry matter than the mean of all *Elymus* entries (94 vs. 34 g per plant averaged for years and locations). The difference in productivity was related to reduced tillering in *Elymus* especially during regrowth. Yield per plant was strongly correlated (r = 0.62–0.81, P < 0.01) with the number of tillers per plant. Differences in productivity were also reflected in leaf blade traits, with *Elymus* having a lower leaf area and mass than orchardgrass. Leaf traits were positively correlated (r = 0.35–0.56, P < 0.05) with plant yield. Some northeastern *Elymus* accessions would probably perform as well as the commercial sources of *Elymus* in conservation plantings.

INTRODUCED SPECIES, such as orchardgrass, account for nearly all of the highly productive forage grasses grown in the northeastern USA. The most frequently grown native grasses in forage systems are warm-season perennials such as switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman). Few, if any, native cool-season grasses have been evaluated as potential forage species in the northeastern USA. Interest in the use of native plant species for conservation and production has increased during recent years because of new federal policies related to invasive species, conservation plantings, and farm programs (Harper-Lore, 1998; Federal Register, 1999).

Virginia wildrye, a perennial cool-season grass native to the northeastern USA, grows along streams, forest margins, and in other moist areas (Pohl, 1947; Hitchcock, 1971). It is recommended as a component in some conservation plantings for revegetation. A recent review described Canada wildrye (*E. canadensis* L.), blue wildrye (*E. glaucus* Buckley), and Dahurian wildrye (*E. dahuricus* Turcz ex Greiseb) as the most noteworthy of the *Elymus* wildryes and briefly mentioned Virginia wildrye for revegetating prairie (Asay and Jensen, 1996). Virginia wildrye is closely related to Canada wildrye. Both species are highly self-fertile allotetraploids ($2n$ = 28) with the SSHH genome constitution (Asay and Jensen, 1996). Very little breeding has been done in either species. In an evaluation of 30 grass species in Saskatchewan, Canada, *E. virginicus* was considered a promising forage grass, but lack of winterhardiness limited its persistence (Lawrence, 1978). Hereafter in this paper, the terms *"Elymus"* and "wildrye" will refer to *E. virginicus*.

Leaf and tiller development are key determinants in the growth, yield, and persistence of the grass sward (Rhodes, 1969, 1971, 1975; Nelson et al., 1977). For example, plants of a tall fescue (*Festuca arundinacea* Schreb.) genotype with high yield per tiller had long erect leaves and a reduced tillering rate, which made for an open sward. Plants of a genotype with low yield per tiller had shorter, lax leaves and a high tillering rate (Zarrough et al., 1983a,b). In perennial ryegrass (*Lolium perenne* L.), selection for longer leaves resulted in greater dry matter production under infrequent cutting, whereas selection for shorter leaves increased yield with frequent defoliation (Rhodes, 1969). Thus, evaluating leaf and tiller traits of potential new forages along with persistence under defoliation is important.

We could not find any information on the use of *Elymus* as forage in the northeastern USA. Greater interest in the use of native grass species in conservation and other plantings has created a need for more information on the suitability of locally adapted native grasses for the northeastern USA. Therefore, our objective was to evaluate several northeastern collections of Virginia wildrye for dry matter yield, persistence, and related morphological characteristics at multiple locations.

MATERIALS AND METHODS

The experiment was conducted at the USDA-NRCS Plant Materials Center in Big Flats, NY (42°N, 76°54′ W, 290 m asl), the Russell E. Larson Agricultural Research Center at Rock Springs, PA (40°48′ N 77°52′ W, 365 m asl), and the USDA-NRCS National Plant Materials Center in Beltsville, MD (39°02′ N, 76°56′ W, 36 m asl) during 2000 to 2002. Soil types were Unadilla silt loam (coarse-silty, mixed, active, mesic Typic Dystrudepts) at Big Flats, Hagerstown silt loam (fine, mixed, semiactive, mesic, Typic Hapludalfs) at Rock Springs, and Iuka sandy loam (coarse, loamy, siliceous, active, acid, thermic, Aquic Udifluvents) at Beltsville. The field sites at Rock Springs and Big Flats were level, whereas the site at Beltsville was on a gentle slope (2–5%) with an eastern aspect. Weather data (Table 1) were recorded at a meteorological station within 2 km of each experimental site.

The Virginia wildrye accessions were collected by the USDA-

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Table 1. Monthly average air temperature and total rainfall at the three northeastern experimental sites during 2001 and 2002 compared with the 30-yr average (1961–1990).

	Big Flats, NY			Rock Springs, PA			Beltsville, MD		
Month	2001	2002	30-yr avg	2001	2002	30-yr avg	2001	2002	30-yr avg
					Air temperature, °C				
March	3.0	2.8	0.9	0.7	3.7	2.5	4.8	7.3	6.0
April	12.1	9.2	7.6	9.4	10.9	8.7	12.6	13.6	11.2
May	8.1	12.4	13.0	14.4	13.8	14.8	16.8	16.6	16.7
June	20.2	20.0	18.0	19.3	21.2	19.5	22.4	22.4	21.7
July	20.4	23.1	20.9	19.5	23.6	21.8	22.1	24.9	24.2
Aug.	22.7	22.8	19.9	21.3	23.2	20.9	23.8	24.3	23.4
Sept.	16.3	19.0	15.9	15.1	19.6	16.8	17.7	20.0	19.6
					Rainfall, mm				
March	96	57	66	107	102	79	85	77	84
April	18	64	71	62	70	74	33	90	84
May	58	122	82	35	164	92	114	61	109
June	51	145	84	138	197	102	137	59	89
July	25	14	82	59	28	92	127	69	104
Aug.	41	28	77	91	64	81	128	84	104
Sept.	94	70	79	80	85	82	55	75	94

NRCS plant materials centers from several northeastern states in 1998 and 1999 (Table 2). Thirteen accessions and two commercial sources (the cultivar Omaha from Stock Seed Co., Murdock, NE; and a Pennsylvania ecotype sold by Ernst Conservation Seeds of Meadville, PA) of wildrye were transplanted into single-row field plots during August 2000 at Beltsville, MD, and September 2000 at Rock Springs, PA, and Big Flats, NY. Two orchardgrass cultivars (Potomac and Pennlate) were included for comparison. Seedlings of each entry were established from seed in the greenhouse at the National Plant Materials Center, Beltsville. Entries were hand transplanted into single-row plots of 10 plants per plot. Each plot of 10 plants contained eight experimental plants and a border plant of wildrye at each end of the row. Border rows of Omaha wildrye alternated with row plots of the accessions. Plants were spaced 30 cm apart within rows, and rows were spaced 30 cm apart. At each location, a plastic weed barrier controlled weed seedlings during establishment. The plastic weed barrier was removed in March or April 2001 after which weeds were controlled by hand and with herbicides.

Soil pH (to a 15-cm depth) was 5.7 at Big Flats, 6.5 at Rock Springs, and 6.1 at Beltsville. Soil P (determined by soil test on 0- to 15-cm deep soil samples) was above optimum at each location, whereas soil K was below optimum. Potassium fertilizer (0–0–60) was applied at 40 kg K ha^{-1} at each location in April 2001. Nitrogen (as ammonium nitrate) was applied at 56 kg ha^{-1} at greenup (late March or early April) in the spring and after the second harvest each year.

Plots were harvested in spring and summer of 2001 and 2002 (Table 3). In 2001 and 2002, late summer and fall regrowth at each location was limited and it was decided not to take a third harvest. *Elymus* accessions were at the late vegetative (internodes elongated to just before boot stage) developmental stage at all harvests. Orchardgrass was headed at the first harvest and was vegetative at the second harvest. At each harvest, the number of tillers was counted on the first two experimental plants in each row. The last two experimental plants in each row were not clipped at the first harvest in each year but were monitored for anthesis date and then clipped after anthesis was reached. The same two plants were monitored each year. The remaining six experimental plants in each row were clipped to a 7-cm height, placed in cloth bags, and dried at 55°C for 48 h to determine dry matter yield per plant. The plot was discarded for yield purposes if fewer than four of the six plants were alive. At Rock Springs, plots in one block were severely damaged by the bluegrass billbug (*Sphenophorus parvulus* Gyllenhal); therefore, this block was discarded. The number of surviving experimental plants of each accession was counted in May 2003 at each location to assess persistence.

At the first harvest each year, 10 tillers of similar morphological developmental stage were taken from the experimental plants in each row. The number of leaves was counted on each tiller and the length and width of each fully elongated leaf blade was measured and leaf area calculated with a laser area meter (CID model CI-203, CID Devices Inc., Vancouver, WA). After measurements, the leaf blades and stems (including the leaf sheath) were dried at 55°C for 48 h and weighed.

The experiment was a randomized complete block design with four blocks at Big Flats and Beltsville and three blocks at Rock Springs. Plot means were used in the analysis of variance. Yield data were the total of two harvests. A combined analysis across years and locations was done on all data. Years and locations were considered random effects and the accessions were considered fixed effects. A combined analysis of

Table 2. Origin of Virginia wildrye accessions evaluated.

Accession or cultivar	Origin	County	Date collected
9085137	MD	Allegany	August 1998
9085141	MD	Montgomery	September 1998
9085127	MD	Washington	August 1998
NJPMC	NJ		1999
9051780	NY	Canojoharie	September 1999
9051781	NY	Tompkins	September 1999
9051783	NY	Montgomery	September 1999
9051784	NY	Cortland	September 1999
9051785	NY	Madison	September 1999
9051786	NY	Chemung	September 1999
9051777	VT	Caledonia	September 1999
9051778	VT	Chittenden	September 1999
9051779	VT	Chittenden	September 1999
PA ecotype	PA	Crawford	
Omaha	NE		

Table 3. Harvest dates of Virginia wildrye and orchardgrass at each location in 2001 and 2002.

Location	2001	2002
Big Flats, NY	23 May 9 July	22 May 10 July
Beltsville, MD	26 April 5 June	23 April 12 June
Rock Springs, PA	21 May 2 July	20 May 11 July

variance indicated significant interactions among years, locations, and entries. The MIXED procedure in SAS (1998) was used to perform the analysis. Denominator degrees of freedom were calculated by the Satterthwaite option of MIXED analysis to determine appropriate degrees of freedom to test fixed effects and interactions of fixed effects. Planned contrasts were used to compare means. The contrasts were (i) average of *Elymus* entries vs. average of orchardgrass cultivars, (ii) average of New York accessions vs. average of Omaha and the commercial ecotype; (iii) average of Maryland accessions vs. average of Omaha and the commercial ecotype; (iv) the accession NJPMC vs. average of Omaha and the commercial ecotype; and (v) average of Vermont accessions vs. average of Omaha and the commercial ecotype. Spearman's rank correlations were used to examine changes in the relative performance of accessions and cultivars among years and locations. Pearson's product moment correlations were used to determine associations between plant yield and morphological traits [leaf area, mass, length, width, specific leaf area (SLA), and tillers per plant]. Statistical significance was declared at the $P < 0.05$ level.

RESULTS AND DISCUSSION

The average date of anthesis for the wildrye accessions and cultivars during the 2 yr ranged from 25 June to 6 July at Beltsville; 3 July to 22 July at Rock Springs; and 13 July to 22 July at Big Flats (Table 4). The general trend was for accessions of more southern origin to mature earlier than those of northern origin. Anthesis date for orchardgrass was 6 to 8 wk earlier than wildrye. Data for orchardgrass anthesis date at New York were lost. Orchardgrass generally begins heading about mid-May in Ithaca, NY (60 km N of Big Flats; D.R. Viands, personal communication, 2003).

Dry Matter Yield per Plant

There were interactions among years, locations, and accessions for yield and tiller data; therefore, data are presented by year and location. Yields were greater at Big Flats than at other locations probably because of better soil and weather conditions. In 2001, rainfall in April, May, and July was well below the long-term average at Rock Springs and Big Flats (Table 1). Rainfall was adequate for most of the 2001 growing season at Beltsville; however, rainfall from September 2001 continuing through 2002 was much below the long-term average. In 2002, spring rainfall was plentiful at Big Flats and Rock Springs, whereas July and August rain was much below average and summer temperatures were above average.

Accessions and cultivars differed for dry matter yield (Table 5). Orchardgrass yielded more dry matter per plant than most wildrye accessions or cultivars. There were a few exceptions at Maryland where orchardgrass yields were lower than other locations and sometimes less than wild rye. The bulk of the dry matter yield for all species occurred in the May harvest.

At all three locations the *Elymus* entries had very little regrowth in late summer and fall of 2001 and 2002. Late summer regrowth yields of orchardgrass were 90 g per plant at Big Flats, 20 g per plant at Rock Springs, and <10 g per plant at Beltsville in 2002. The *Elymus* accessions with harvestable regrowth yielded <10 g per plant in September 2002. The severe drought coupled with very sandy soil at Beltsville caused significant plant death in both *Elymus* and orchardgrass.

The New York accessions did not differ in yield from Omaha and the commercial ecotype at Big Flats in both years (Table 5). The Maryland accessions and NJPMC yielded less than Omaha wildrye and the commercial

Table 4. Average date of anthesis of wildrye and orchardgrass at New York, Maryland, and Pennsylvania.

Accession or cultivar	Origin	New York	Maryland	Pennsylvania
9085137	MD	22 July	25 June	7 July
9085141	MD	16 July	27 June	7 July
9085127	MD	15 July	22 June	3 July
NJPMC	NJ	13 July	3 July	15 July
9051780	NY	19 July	4 July	17 July
9051781	NY	19 July	2 July	17 July
9051783	NY	18 July	5 July	20 July
9051784	NY	18 July	4 July	19 July
9051785	NY	19 July	30 June	16 July
9051786	NY	17 July	6 July	16 July
9051777	VT	19 July	1 July	12 July
9051778	VT	19 July	5 July	19 July
9051779	VT	20 July	3 July	22 July
PA ecotype	PA	19 July	1 July	19 July
Omaha	NE	17 July	30 June	10 July
Pennlate orchardgrass			22 May	17 June
Potomac orchardgrass			22 May	17 June

Table 5. Dry matter yields of Virginia wildrye accessions and two orchardgrass (OG) cultivars at three locations. Data are the sum of two harvests in each year. Data are least squares means of four replicates at New York and Maryland and three replicates at Pennsylvania.

Accession or cultivar	Origin	New York 2001	New York 2002	Maryland 2001	Maryland 2002	Pennsylvania 2001	Pennsylvania 2002
		g of dry matter per plant					
9085137	MD	34	23	32	15	34	
9085141	MD	46	38	34	20	35	18
9085127	MD	36	18	29	16	34	6
NJPMC	NJ	8	10	32	35	18	16
9051780	NY	57	53	40	29	32	27
9051781	NY	39	49	32	13	36	32
9051783	NY	52	54	37	27	42	45
9051784	NY	54	54	38	36	29	36
9051785	NY	30	31	24	10	28	14
9051786	NY	55	48	54	37	43	47
9051777	VT	46	41	32	22	26	28
9051778	VT	37	47	27	18	34	29
9051779	VT	38	43	40	47	33	49
PA ecotype	PA	52	48	31	16	30	31
Omaha	NE	55	52	34	25	31	48
Pennlate OG		118	182	31	45	46	141
Potomac OG		104	176	57	41	51	138
Elymus mean		43	41	34	24	32	31
CV %		9	12	11	20	19	13
		Contrasts†					
Elymus vs. OG		**	**	**	**	NS	**
NY vs. CHK		NS	NS	NS	NS	NS	NS
NJPMC vs. CHK		**	**	NS	*	NS	**
MD vs. CHK		**	**	NS	NS	NS	**
VT vs. CHK		**	NS	NS	NS	NS	NS

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: *Elymus* vs. OG, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. CHK, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. CHK, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. CHK, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. CHK, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

Table 6. Spearman rank correlation coefficients among locations and years for plant yields.

	NY 2002	MD 2001	MD 2002	PA 2001	PA 2002
NY 2001	0.87**	0.56*	0.58*	NS	0.69**
NY 2002		0.49*	0.51*	0.49*	0.78**
MD 2001			0.65*	NS	0.55*
MD 2002				NS	0.69**
PA 2001					0.55*

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.

wildrye ecotype at Big Flats in both years. The Vermont accessions yielded less than the commercial wildryes in 2001.

There were no differences in yield between groups of accessions and the commercial wildrye entries at Beltsville and Rock Springs in 2001 (Table 5). In 2002, NJPMC yielded more than the commercial wildryes at Beltsville, whereas at Rock Springs NJPMC yielded less. The New York, Maryland, and Vermont accessions also yielded less than the commercial wildryes at Rock Springs.

Accessions 9051786 and 9051783 maintained relatively high dry matter yield at all locations in both years (Table 5). At Big Flats, most of the New York and Vermont accessions and the commercial cultivars maintained their productivity from 2001 to 2002. At Beltsville, only four accessions maintained or improved in yield in 2002 compared to 2001. In general, it appeared that the northern accessions performed better at New York and Pennsylvania than more southerly adapted *Elymus* accessions. There was no clear pattern of regional adaptation among the *Elymus* accessions at Maryland.

Correlation analysis indicated that 2001 yields at Pennsylvania were not correlated with yields at other locations in 2001 and the Maryland location in 2002 (Table 6). Most of the New York accessions (9051780, 9051781, 9051783, and 9051784) ranked much differently in Pennsylvania than in New York or Maryland in 2001 (Table 5). The accession 9051780 performed well in New York compared with other *Elymus* accessions, whereas 9051786 seemed to do well at all locations.

Accessions differed in survival. Overall, *Elymus* survival was lower than that of orchardgrass (Table 7). At New York, the NJPMC entry had very poor survival compared with the other accessions. Survival was poor at Maryland because of the severe drought during 2002. Soil at the Maryland site was very sandy with a low water-holding capacity, which exacerbated the drought. At Maryland, accession 9051778 from Vermont and 9051785 from New York had the poorest survival. At Pennsylvania, the Maryland accessions and the commercial ecotypes had lower survival than other *Elymus* accessions.

Tillers per Plant

In nearly all instances, orchardgrass produced more tillers per plant than *Elymus* (Table 8). Among the *Elymus* entries, the New York accessions did not differ from the commercial *Elymus* entries, with the exception of Harvest 1 in 2002 at Big Flats and Harvest 2 in 2002 at Rock Springs. The NJPMC accession had fewer tillers

Table 7. Percent survival of Virginia wildrye accessions and two orchardgrass (OG) cultivars at New York, Maryland and Pennsylvania. Data are least squares means of four replicates at New York and Maryland and three replicates at Pennsylvania.

Accession	Origin	NY	MD	PA
		Percent survival		
9085137	MD	66	47	25
9085141	MD	81	69	62
9085127	MD	60	62	42
NJPMC	NJ	32	66	92
9051780	NY	66	41	71
9051781	NY	76	28	79
9051783	NY	69	31	83
9051784	NY	66	47	83
9051785	NY	66	10	71
9051786	NY	72	59	100
9051777	VT	69	41	88
9051778	VT	79	28	83
9051779	VT	57	75	88
PA ecotype	PA	66	41	58
Omaha	NE	72	44	54
Pennlate OG		79	75	100
Potomac OG		79	81	92
Elymus mean		66	46	72
SE		8.0	18.9	9.2
		Contrasts†		
Elymus vs. OG		*	**	**
NY vs. CHK		NS	NS	**
NJPMC vs. CHK		**	NS	**
MD vs. CHK		NS	NS	NS
VT vs. CHK		NS	NS	**

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
† Contrasts were: *Elymus* vs. OG, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. CHK, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. CHK, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. CHK, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. CHK, average of Vermont accessions vs. average of Omaha and the commercial ecotype.
NS, not significant.

per plant than the commercial *Elymus* entries at Big Flats, whereas there were generally no differences at Beltsville or Rock Springs. The Maryland accessions did not differ from the commercial *Elymus* entries at Harvest 1 in Big Flats; however, the Maryland accessions had fewer tillers at subsequent harvests. At Beltsville, the Maryland accessions produced as many or more tillers than the commercial *Elymus* entries. At Rock Springs, the Maryland accessions had more tillers per plant than the commercial entries at Harvest 1 in 2001; however, the accessions had fewer tillers at other harvests. The Vermont accessions generally did not differ in tiller number from the commercial entries with the exception of Big Flats in 2001 and Harvest 2 at Rock Springs in 2002.

Elymus accessions had only one-half or less of the number of tillers at Harvest 2 compared with Harvest 1, whereas orchardgrass maintained or increased tiller numbers between harvests (Table 8). Differences in tiller patterns between orchardgrass and *Elymus* may have been due to the proportion of tillers with elevated meristems. Visual observations of plants indicated that *Elymus* tillers tended to be more synchronous in development and most tillers had elevated the meristem before harvest, whereas orchardgrass maintained many more unelongated, vegetative tillers. Vegetative tillers continue to grow after defoliation, whereas tillers with elevated

Table 8. Number of tillers per plant of Virginia wildrye accessions and two orchardgrass (OG) cultivars at each harvest during three years and at three locations. Data are least squares means of four replicates at New York and Maryland and three replicates at Pennsylvania.

		New York				Maryland				Pennsylvania			
		2001		2002		2001		2002		2001		2002	
Accession or cultivar	Origin	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
9085137	MD	110	17	58	27	132	38	49	35	76	12		
9085141	MD	121	51	102	63	150	44	94	45	90	22	100	51
9085127	MD	119	11	69	32	125	21	62	38	93	21	84	25
NJPMC	NJ	32	9	15	10	73	33	94	69	45	20	39	34
9051780	NY	126	62	149	92	149	43	113	75	78	29	144	138
9051781	NY	84	44	110	64	82	35	61	40	74	25	81	80
9051783	NY	97	40	135	82	97	37	92	57	71	34	166	82
9051784	NY	113	65	150	76	108	36	114	58	62	27	122	54
9051785	NY	69	34	71	52	69	17	41	24	67	15	43	26
9051786	NY	146	70	176	104	132	65	130	81	86	38	150	98
9051777	VT	89	34	84	62	69	30	51	41	52	18	102	69
9051778	VT	94	31	92	51	69	26	78	33	67	28	102	53
9051779	VT	78	21	74	44	89	36	123	69	36	27	107	59
PA ecotype	PA	104	44	105	56	96	34	69	34	66	19	114	47
Omaha	NE	112	54	105	82	96	44	103	60	58	38	124	58
Pennlate OG		124	170	247	209	55	101	96	130	53	92	184	177
Potomac OG		70	124	198	186	88	134	90	94	58	84	179	243
Elymus mean		100	39	100	60	102	36	85	51	68	25	106	59
CV%		19	37	23	36	22	44	40	28	20	35	35	37
						Contrasts†							
ELY vs. OG		NS	**	**	**	**	**	NS	**	*	**	**	**
NY vs. CHK		NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
NJPMC vs. CHK		**	**	**	**	NS	NS	NS	*	NS	NS	**	NS
MD. vs. CHK		NS	*	*	*	**	NS	NS	NS	**	NS	NS	NS
VT vs. CHK		*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: ELY vs. OG, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. CHK, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. CHK, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. CHK, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. CHK, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

meristems must be replaced by new tillers that develop from axillary buds. In some, but not all instances, defoliation of reproductive tillers can stimulate axillary bud growth (Richards et al., 1988; Olson and Richards, 1988). Regrowth from axillary buds, however, is slower than regrowth from intercalary and leaf primordial meristems (Briske, 1986). In some *Agropyron* species, the lack of tillering after defoliation was related to a differential pattern of photosynthate allocation to shoots and roots. Crested wheatgrass [*Agropyron cristatum* (L.) Gaetrn.], a defoliation-tolerant species that tillers freely after cutting, allocated more photosynthate to shoot growth, whereas the defoliation-sensitive species bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Löve] allocated more photosynthate to roots than shoots (Dahl, 1995). Differences in root/shoot partitioning, however, may be the result rather than the cause of differences in tillering (Richards, 1984). Wilman et al. (1994) reported that orchardgrass maintained the shoot apices near ground level and also had relatively thick tiller bases, which may protect the shoot apices from desiccation.

The number of tillers per plant was strongly correlated with yield ($r = 0.60$ for Harvest 1 and $r = 0.81$ for Harvest 2, $P < 0.01$). In space-planted swards of grasses, tiller number generally influences forage yield more than does tiller mass until a dense, closed sward forms (Zarrough et al., 1983a, 1983b; Montero and Jones, 1992). Tillering and leaf blade traits in space-planted grasses may not necessarily be the same in a dense sward.

Leaf Blade Traits

A combined analysis indicated a year × location × entry interaction in all leaf blade traits caused mainly by changes in the rank of the orchardgrass cultivars in each year. When the orchardgrass cultivars were dropped from the analysis there was only a location × entry interaction (data not shown). Thus, the location × entry interaction means are presented (Table 9). *Elymus* leaves were shorter, slightly wider, and had a lower leaf area and leaf mass than orchardgrass. Leaves of the New York wildrye accessions and NJPMC had a greater leaf area than the commercial wildryes because of longer leaves. The Maryland accessions had lower leaf area and leaf mass than the commercial wildryes, whereas the Vermont accessions had larger leaves than Omaha wildrye or the commercial wildrye ecotype.

Accession 9051779 generally had greater individual leaf area than other accessions because of wider leaves. Orchardgrass had greater leaf mass than *Elymus* generally because of longer leaves and generally greater leaf area. Combined for years and locations, all leaf morphology characteristics were positively correlated with yield. Pearson correlations of yield with leaf morphology were as follows: leaf mass, $r = 0.35$; leaf area, $r =$

Table 9. Leaf morphology of Virginia wildrye accessions and two orchardgrass (OG) cultivars at three locations. Data are averages of two years.

Accession or cultivar	Origin	Area			Length			Width			Mass			Specific leaf area		
		NY	MD	PA	NY	MD	PA	NY	MD	PA	NY	MD	PA	NY	MD	PA
		cm^2 $leaf^{-1}$			cm $leaf^{-1}$						mg DM $leaf^{-1}$			cm^2 g^{-1} leaf DM		
9085137	MD	13.7	10.9	13.9	19.1	16.2	19.3	1.0	0.9	1.0	37.1	32.8	44.9	369	331	312
9085141	MD	12.0	12.0	12.2	17.8	16.0	17.2	0.9	1.1	1.0	39.8	35.5	37.8	337	335	324
9085127	MD	12.5	13.1	12.2	17.1	15.9	16.3	1.0	1.1	1.0	33.1	39.5	40.1	382	326	305
NJPMC	NJ	17.9	17.4	16.6	21.9	21.8	21.5	1.1	1.1	1.0	55.3	61.4	63.6	323	298	264
9051780	NY	15.3	15.0	16.0	20.2	19.0	19.2	1.0	1.0	1.2	39.1	41.5	47.5	395	361	342
9051781	NY	15.5	13.6	16.3	19.9	17.4	20.0	1.1	1.1	1.1	48.3	48.2	56.9	326	285	290
9051783	NY	17.3	16.0	18.2	23.4	18.7	21.4	1.1	1.1	1.2	53.3	51.0	60.2	325	311	306
9051784	NY	16.6	17.3	18.8	21.3	18.3	20.7	1.0	1.2	1.5	49.8	54.8	64.3	336	317	293
9051785	NY	14.2	13.8	14.8	19.0	17.3	18.0	1.0	1.0	1.1	38.3	45.9	50.0	345	299	297
9051786	NY	13.9	13.6	14.1	19.5	18.4	19.3	0.9	1.0	1.0	39.5	41.8	46.4	355	323	309
9051777	VT	15.8	15.3	18.4	19.6	18.0	20.6	1.1	1.1	1.2	45.8	53.5	67.4	353	283	278
9051778	VT	16.4	15.3	17.6	20.0	18.1	20.1	1.1	1.1	1.2	51.0	50.4	61.1	327	302	290
9051779	VT	21.6	20.1	21.8	20.8	19.0	20.3	1.3	1.4	1.5	64.4	66.4	77.6	334	300	282
PA ecotype	PA	15.5	14.5	16.2	20.2	18.1	20.2	1.0	1.0	1.1	45.0	47.9	56.4	349	303	291
Omaha	NE	12.4	12.9	12.4	17.5	17.6	16.9	1.0	1.1	1.0	34.4	44.6	43.3	373	293	289
Pennlate OG		19.9	20.8	18.4	28.6	26.0	25.8	0.9	1.1	1.0	62.7	74.0	60.5	322	284	305
Potomac OG		16.2	19.8	20.2	25.1	26.3	27.6	0.8	1.1	1.0	50.5	70.0	66.3	326	285	310
Elymus mean		15.4	14.7	16.0	19.8	18.0	19.4	1.0	1.1	1.1	44.9	47.7	54.5	349	312	299
CV%		11.8	12.5	12.5	9.7	9.2	8.0	8.3	14.3	10.6	17.8	14.8	15.8	10	8	8
								Contrasts†								
ELY vs. OG		**	**	**	**	**	**	**	NS	**	**	**	**	*	NS	NS
NY vs. CHK		**	*	**	NS	**	*	NS	NS	*	*	NS	NS	NS	NS	*
NJPMC vs. CHK		**	**	*	**	**	**	NS	NS	NS	**	**	**	*	NS	NS
MD. vs. CHK		NS	**	NS	**	NS	NS	NS	NS	**	NS	**	**	NS	NS	**
VT vs. CHK		**	**	**	NS	*	**	**	*	**	**	**	**	*	**	NS

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: ELY vs. OG, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. CHK, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. CHK, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. CHK, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. CHK, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

0.56; leaf length, $r = 0.49$; leaf width, $r = 0.35$; and specific leaf area, $r = 0.54$ ($P < 0.01$ for all coefficients).

CONCLUSIONS

Most *Elymus* accessions performed similarly to the commercially available cultivar and ecotype. *Elymus* was not as productive as orchardgrass with dry matter yields often less than one half of orchardgrass. The difference in productivity was mainly related to a reduced capacity for tillering in Elymus, especially in regrowth. Considering other grass species that are available, *Elymus* may be better suited for conservation plantings than forage when used in the northeastern USA.

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